

LABORATORY EVALUATION OF KILN CORROSION CAUSED BY THE DRYING OF WETWOOD

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Introduction

It is a long, commonly held view that kiln drying of certain species leads to excessive kiln corrosion. The corrosive effects of drying wood with high extractive concentrations and/or acidity on metallic parts has indeed been documented (2, 5, 6, 7, 8). The corrosive effect of western red cedar on steel and aluminum, in particular, has been shown to be due to the presence of tropolone extractives (3, 4).

The drying of lumber containing wetwood is also generally believed to cause excessive kiln corrosion. As noted in the very comprehensive review by Ward and Pong (1980), wetwood is a type of heartwood in standing trees which has been internally infused with an excessively high moisture content. In addition to this difference in heartwood moisture content, wetwood also differs from normal wood in a number of other physical and mechanical properties, including the fact that it is more difficult to dry. The cause of wetwood formation is still not exactly understood but it has been attributed to bacterial infection, wound injury and/or normal age-growth formation.

Wetwood is classified as being generally prevalent in western hemlock, and white, grand, and subalpine fir. It has scattered prevalence in other western coniferous species such as sugar and ponderosa pine, redwood, and western red cedar. Despite its wide occurrence in these varied softwood species, there is no actual data in the literature to either confirm or disprove the opinion that its drying actually does cause excessive corrosion.

Excessive kiln corrosion is important for two reasons. The first and most obvious is that it can lead to shortened service life of the metal kiln structure and its various compounds thereby causing higher maintenance costs. Less apparent but perhaps even more important in the long run is that excessive corrosion very significantly affects the overall efficiency of the finned tube heating coils in the kiln. Lowered heat transfer rates mean increased steam consumption and greater overall heating or energy costs. For this reason, a cooperative project between the U.S. Forest Service Pacific Northwest Forest and Range Experiment Station and the University of California-Berkeley Forest Products Laboratory was set up with the purpose of:

experimentally quantifying the corrosiveness of
wetwood using white fir [Abies concolor (Gord and
Glend)] as a reference species.

Test Procedure

The original test concept was to expose separately small metal coupons to the drying vapors of normal and wetwood containing material; corrosion being defined as the mass loss of the coupons as a result of the exposure.

Aluminum (6061-T6) and steel (1018 hot rolled) coupons 50 mm in length by 25 mm in width by 1.6 mm in thickness were used. Ten coupons for each type of metal were used in each test corrosion test. The individual coupons were processed as follows:

1. Sanding with emery cloth
2. Cold stamped with a test run number and individual coupon number (1 through 10)
3. Measured for length, width, and thickness
4. Ultrasonically cleaned in distilled water for 0.5 hour
5. Dried in acetone
6. Weighed
7. Stored in an air tight desiccator until used.

After the end of the corrosion tests, steps 3 through 8 were again repeated in order to obtain the mass change.

Ultimately, two distinctly different test methods were finally used. The first involved exposing coupons in a small experimental kiln as per the original objective. As will be shown shortly, this procedure was inconclusive and an accelerated exposure test was used. The experimental procedures of each of these are discussed separately after discussion of the raw material.

Raw Material

The lumber used in the kiln runs and the accelerated corrosion tests was obtained directly from the green chain of a sawmill in Northern California and transported immediately to the Forest Products Laboratory. Ten boards, 12 ft. in length, either 2x4's or 2x6's, were selected for each of the following three types of material:

1. Douglas-fir heartwood
2. White fir sapwood
3. White fir sinker (wetwood).

Decisions as to sinker versus sapwood type material identification were made by the authors with advice of the green chain foreman. Three different types of wood were tested for a specific reason. The white fir wetwood (sinker stock) was the primary material of interest, obviously. Douglas-fir heartwood was selected as the control material as this species is not thought to be corrosive at all. White fir sapwood was also included as a control, that is, to insure that white fir itself is not more corrosive than Douglas-fir. Comparisons between the white fir wetwood and sapwood and then Douglas-fir would permit establishing the true corrosiveness of wetwood.

Upon arrival at the Laboratory, each board was processed as follows:

1. Six inches of material were sawn from each board end to remove the effects of excessive end drying.

2. Two 20-inch long pieces were then cut off each board and their ends end-sealed.
3. A one-inch long moisture content wafer was cut adjacent to each end of the 20-inch piece in order to obtain the initial moisture content of each piece.
4. The material was then wrapped in plastic and stored in a cold room (38°F) until tested.

Kiln Exposures

The kiln drying tests were carried out in a laboratory micro-kiln having a total capacity of 35 bd. ft. Each kiln charge consisted of ten 20-inch long end-sealed samples, each piece having come from a different board. The courses within the charge were separated by 0.75 inch thick stickers. The air velocity on the leaving air side was set at 450 fpm.

The coupons, during a run, were positioned in a vertical row via a wire and nylon spacer immediately behind the leaving air side of the charge so that they were exposed to the maximum extent to the wood vapors. The kiln used is particularly air tight, further facilitating maximum wood vapor exposure. The coupons were removed from the kiln every 24 hours and reweighed to determine the rate of corrosion development, if any.

The kiln schedules used for the Douglas-fir heartwood are given in Table 1 and that for white fir sapwood and white fir sinker are given in Table 2.

Accelerated Exposure Tests

Because corrosion is a relatively slow process with small mass changes, it is generally measured using an accelerated test. The test used was ASTM test G31-72 "Laboratory Immersion Corrosion Testing of Metals" (ASTM, 1979). This standardized procedure had been used before (Venturino *et al.*, 1978) and was found to be convenient and effective. It is also the standard corrosion test in the United States.

The lumber used in these tests was from the same batch used in the kiln atmosphere exposure tests and will not be discussed in detail here. Boards for each species were stored in a cold room (38°F) wrapped in plastic until processed. Appropriate lengths were then sawn in 1 inch cubes and converted to sawdust using a Wiley mill. Once 10-12 lbs. of sawdust for each of the three types of material had been prepared, it was again passed through the Wiley mill but using a 60 mesh screen.

Testing was carried out in a 5000 ml glass reaction kettle heated by a regulated heater. The kettle was equipped with a water cooled reflux condensor and an immersion thermometer. Each test run used 10 coupons (one material type) supported on a stainless steel support rack made for those tests (Figure 1). The support rack was designed so that the coupons were fully submerged throughout the test duration.

The test solution consisted of either 100 or 200 g of sawdust placed in 2 liters of distilled water. Solution temperature was maintained at 160°F. Each test lasted for 7 days; a fresh sawdust/water solution was used every 24 hours. In this

way, the coupons were frequently exposed to material of maximum corrosibility.

Corrosion rate was calculated as follows:

$$CR = (K \times W) / A \times T \times D$$

Where:

CR = corrosion rate (in inches corroded per year)

K = 3450 (constant for conversion to inches/year)

T = time of exposure to solution in hours

A = surface area of coupon in cm^2 edges

W = weight loss in g

D = density of coupon in g/cm^3

Results and Discussion

Kiln Exposure Tests

Data on the average initial and final moisture contents for the three kiln runs are given in Table 3. These data simply confirm that the material was indeed fresh (or green) at the start of the kiln tests and was dried to a suitable final moisture content. It also shows that the initial moisture content of the white fir sinker charge was greater than that of the corresponding sapwood (approximately 20%) as is expected.

Data on the initial and final masses of the steel and aluminum coupons (after ultrasonic cleaning) for all three kiln runs are given in Table 4. These data show that there was no significant mass loss for either metal type or for any of the three types of wood tested. It was expected that the coupons tested with the white fir sinker stock would be corroded and would have undergone measurable mass loss. This quite clearly was not the case.

While this could perhaps be used as evidence that white fir wetwood is not as corrosive as thought, it is by no means conclusive evidence. These results may, rather, simply show that the corrosion rate is too slow to be quantified by a single kiln exposure. It was, unfortunately, beyond the scope of this study to make multiple kiln exposure runs.

The inconclusiveness of the kiln tests precipitated using a second and distinctly different test approach, i.e., an accelerated test.

Accelerated Exposure Tests

The results of the tests carried out using the three different materials are summarized in Table 5. With Test 1, the solution consisted of 100 g sawdust in 2000 ml water. In the remaining three tests, 200 g of sawdust was used. The corrosion potential of the solution for the last three tests was therefore twice that of the first test. Valid comparisons can be made between these latter three runs.

With respect to the aluminum coupons, the white fir wetwood exhibited the highest rate of corrosion (0.0062 in./yr.) and

white fir sapwood the lowest (0.0004 in./yr.). The Douglas-fir sapwood corrosion rate was about 33% less than the white fir wetwood and 10x greater than the white fir sapwood. In the case of aluminum, therefore, wetwood type material was found to be the most corrosive although not greatly more so than Douglas-fir.

With the steel coupons, an entirely different result was observed. The Douglas-fir sapwood had the highest corrosiveness (0.0420 in./yr.); this being 3.65 times greater than that of the wetwood and 3.04 times the white fir sapwood. The wetwood, with steel, had the lowest degree of corrosion (0.0115 in./yr.). As expected, the steel coupons were corroded more than the aluminum coupons; the ratio of steel to aluminum ranging from 1.85 for the wetwood to 34.5x for the white fir sapwood.

Although limited in number of tests, the influence of amount of sawdust to structural material used in the tests can be assessed by comparing Test 1 (100 g/2000 ml) to Test 4 (200 g/2000 ml). The results are inconclusive since doubling the potential quantity of corrosion causing material induced a 10-fold increase in the corrosion rate of the aluminum and had no effect at all with the steel coupons.

As noted in the introduction, a liquid phase test was selected over a vapor phase test since it is generally harsher. A vapor test would in reality be the condition one would find in a dry kiln. Previous data obtained in our Laboratory presented in Table 6 justifies this selection. These data on corrosion tests using the same procedure gives data for incense cedar heartwood and a commercial stain used to dye incense cedar pencil slats. Comparing sawdust material only, the liquid test is 2.42 times more corrosive than the vapor phase for steel and 26.8 times more corrosive for aluminum.

These data can also be used to compare the corrosiveness of wetwood to incense cedar, the latter being one of the species known to have an easily observable excessive corrosiveness in dry kilns. This is due to the tropolone fraction of the incense cedar extractive content. The corrosiveness of incense cedar and wetwood when compared for a liquid phase test only shows that the wetwood was only 0.53 times as corrosive as incense cedar with steel and 0.27 times for aluminum. It should be noted that the quantity of incense cedar sawdust to liquid in the previous tests was 255 g/2000 ml.

One must conclude when viewing all of these data from both types of tests and from the widely accepted corrosive nature of incense cedar that wetwood type material was not found to be highly more corrosive. These results, however, were obtained from either short or accelerated tests which are difficult to interpret and extrapolate to real "in service" conditions. The ultimate resolution of the corrosiveness of wetwood would have to be determined by longer term actual "in kiln" material testing.

Summary and Conclusions

1. Using a single exposure "in kiln exposure" test and an "accelerated immersion" test, wetwood of white fir was not found to be more corrosive than normal white fir as Douglas-fir.

2. In the immersion tests used, the action of the pH of the white fir wetwood may have been offset by the considerable buffering action of white fir when used in an aqueous solution.
3. Resinous containing species such as the pines and Douglas-fir impart some corrosion resistance through the coating action of condensed resins on the internal parts of the kiln.
4. Finally, the best and probably only conclusive means for establishing wetwood corrosiveness would be through a long term coupon exposure in a commercial kiln.

Literature Cited

1. American Society for Testing and Materials. 1978. Laboratory immersion corrosion testing of metals. Part No. 10. Standard G31-72.
2. Barton, G. M. 1972. How to prevent dry kiln corrosion. Can. For. Ind. 92(4):27-29.
3. Barton, G. M. and B. F. MacDonald. 1971. The chemistry and utilization of western red cedar. Can. For. Serv., Rep. Publ. 1023, revised.
4. Bramhall, G. and G. M. Barton. 1976. Laboratory studies kiln corrosion damages. British Columbia Lumberman. 61(3): 52-53.
5. Gray, V. R. and M. E. Wheeler. 1959. Acidity and corrosive effects of redwood and whitewood. Timber Research Development Assoc. Research Report C/RR/7.
6. MacLean, H. and J. A. F. Gardner. 1951. Deterioration of wooden dry kilns used for drying western hemlock lumber. The Lumberman 78(12):88-90.
7. MacLean, H., J. A. F. Gardner. 1953. Aluminum sheet linings for wooden kilns. The Lumberman 80(12):100.
8. Venturino, J. A., D. G. Arganbright, and E. Zavarin. 1978. Analysis of Hudson Lumber Company's Kiln corrosion problem. Univ. of Calif. Forest Prod. Laboratory Techn. Report 35.01.213 Progress Rept. 1 & 2.
9. Ward, J. C. and W. Y. Pong. 1980. USDA For. Serv. General Tech. Report PNW-112. 56 pp.

Table 1. Kiln schedule used for 2x4 Douglas-fir heartwood

Time (hrs.)	Dry bulb temperature (°F)	Wet bulb temperature (°F)
0-12	145	138
12-24	145	135
24-36	150	135
36-48	150	130
48-60	155	135
60-72	155	130
72-75	160	135

Table 2. Kiln schedule used for 2x4 white fir sapwood and white fir sinker (wetwood)

Time (hrs.)	Dry bulb temperature (°F)	Wet bulb temperature (°F)
0- 24	160	150
24- 48	160	150
48- 72	180	165
72- 96	190	170
96-120	190	160
120-144	190	150
144-168	190	140

Table 3. Initial and final moisture content for the three kiln runs (values in parentheses are standard deviations).

	Average Initial Moisture Content (%)	Average Final Moisture Content (%)
<u>Kiln Run 1</u>		
Douglas-fir heartwood	36.0 (7.69)	10.21
<u>Kiln Run 2</u>		
White fir sapwood	144.8 (36.66)	3.42
<u>Kiln Run 3</u>		
White fir sinker	163.95 (35.80)	6.04

Table 4. Average initial and final masses of the aluminum and steel coupons used in the kiln runs (values in parentheses are standard deviations).

	Steel		Aluminum	
	Mass Initial (g)	Mass Final (g)	Mass Initial (g)	Mass Final (g)
<u>Kiln Run 1</u>				
Douglas-fir heartwood	13.893 (0.092)	13.887 (0.084)	5.171 (0.010)	5.173 (0.021)
<u>Kiln Run 2</u>				
White fir sapwood	13.904 (0.127)	13.900 (0.131)	5.173 (0.020)	5.172 (0.020)
<u>Kiln Run 3</u>				
White fir sinker (wetwood)	13.891 (0.071)	13.890 (0.072)	5.175 (0.029)	5.175 (0.029)

Table 5. Results of accelerated corrosion tests on liquid immersed steel and aluminum coupons

Test No.	Length of exposure (hrs.)	Type of wood in test	Amount: wood water (g) (ml)		Calculated corrosion Rate (in./yr.)	
			wood (g)	water (ml)	Aluminum	Steel
1	168	White Fir wetwood	100	2000	0.0005	0.0115
2	168	White Fir sapwood	200	2000	0.0004	0.0138
3	168	Douglas-Fir sapwood	200	2000	0.0043	0.0420
4	190	White Fir wetwood	200	2000	0.0062	0.0115

Table 6. Corrosion rates with incense cedar sawdust, and pencil slat stain for liquid and vapor tests (Venturino et al., 1978)

Type of test		Corrosion rate (in./yr.) for:	
		Aluminum	Steel
Liquid Phase	stain	.0019	.0147
	sawdust	.0233	.0218
Vapor Phase	stain	.00033	.00047
	sawdust	.00087	.0090

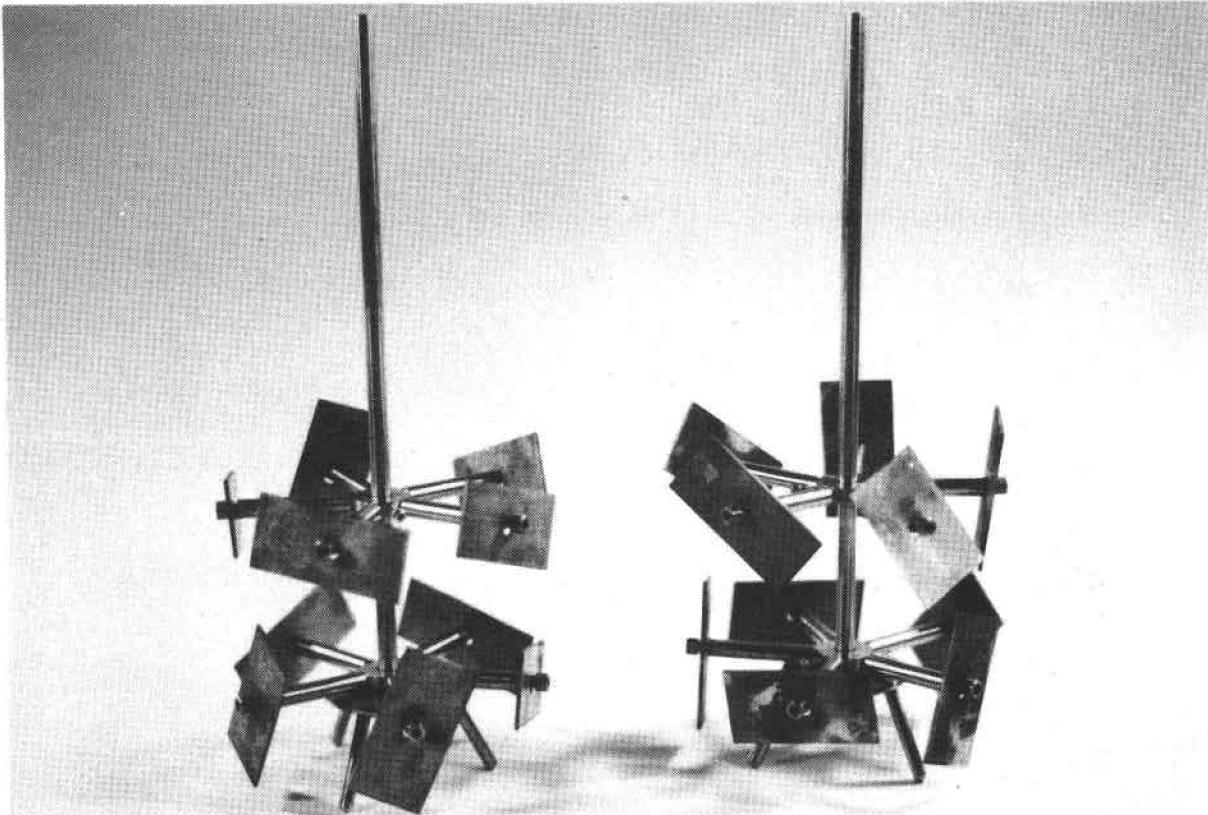


Figure 1. Stainless Support Rack